

## WIRELESS COMMUNICATION

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from provisional application Serial No. 60/193,008, filed 03/29/00.

### BACKGROUND OF THE INVENTION

The invention relates to electronic devices, and more particularly to wireless communication.

Demand for wireless information services via cell phones, personal digital assistants (PDAs), and Internet appliances (IA) plus wireless networking among notebook computers is rapidly growing. Various protocols for wireless communication have been proposed, including the WCDMA for cellular systems, Bluetooth for local wireless networking at moderate data rates and low cost, and 802.11 for wireless networking at high data rates (e.g., 20 Mbps). WCDMA has both time division duplex (TDD) and frequency division duplex (FDD) modes of operation; Bluetooth uses slow frequency hopping over roughly 30-80 1-MHz channels but in a TDD mode of alternate master and slave transmissions, and 802.11 has carrier sense multiple access with collision avoidance (CSMA/CA) which is a TDD-like mode of two or more devices using the same channel at different times.

In a TDD system a pair of devices communicating may called a master and a slave and the transmission from master to slave termed the downlink and the transmission from the slave to the master termed the uplink. The master can estimate the channel between the master and slave by analysis of received signals from the slave, and the master can then use such estimates to adjust features of its transmissions, such as code rate, power, information rate, antenna weight adjustment, and so forth. However, the master measures the uplink channel rather than the needed downlink channel. As illustrated in Figure 2, the uplink channel is composed of the slave power amplifier followed by the physical channel followed by the low noise amplifier of the master; in contrast, the

downlink channel is composed of the master power amplifier followed by the physical channel followed by the low noise amplifier of the slave. Although there are many gains and phase shifts associated with all the elements in both the master and slave for both the transmitting and receiving front ends, Figure 2 lumps these factors generally as "power amplifier" and "low noise amplifier".

The master needs the downlink channel estimate to maximize the throughput of its transmissions to the slave (for example, to use TxAA or STD). It is not easy to match the attenuations and phase shifts in the master and slave amplifiers, and so the channel measured by the master (the uplink channel) will be different than the one the master will use for transmission (the downlink channel) as shown in Figure 2. This is a problem for current systems.

## SUMMARY OF THE INVENTION

The present invention provides a wireless system with a master and/or a slave which employs a calibration method to adjust channel estimates.

This has advantages increasing efficiency of TDD-like transmissions.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a preferred embodiment flow.

Figure 2 illustrates uplink and downlink channels.

Figure 3 shows transmission adaptation.

Figure 4 illustrates a wireless transceiver.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

### 1. Overview

Preferred embodiment systems provide for time division duplex (TDD) communication system channel estimation by use of initial channel measurements followed by updates using calibration factors. In particular, a downlink channel estimate is taken equal to an uplink channel measurement adjusted by (presumably) constant calibration factors. Thus when the physical channel changes, the changes apply equally to the uplink and downlink, so measurement of uplink changes alone allows for performing corresponding changes in a downlink estimate. A transceivers communicating over the downlink channel may then adjust its modulator (modulation filter) to optimize transmission on the downlink channel.

### 2. preferred embodiments

Figure 1 illustrates the flow for a first preferred embodiment method of channel estimation and use in a master-slave system. The channel estimation may be just the filter coefficient estimation in the receiving matched filter. In more detail, the method proceeds as follows. First, with initial communication between the master and the slave, the master sends a packet to the slave which the slave uses to measure the downlink channel as

$$G_{DL} = G_{M-PA} * \rho * G_{S-LNA} .$$

$$\theta_{DL} = \theta_{M-PA} + \theta + \theta_{S-LNA} .$$

where  $G_{DL}$  and  $\theta_{DL}$  are the overall downlink gain and phase shift, respectively;  $G_{M-PA}$  and  $\theta_{M-PA}$  are the gain and phase shift of the master power amplifier;  $\rho$  and  $\theta$  are the physical channel attenuation and phase shift, respectively; and  $G_{S-LNA}$  and  $\theta_{S-LNA}$  are the gain and phase shift of the slave low noise amplifier, respectively. This packet may be transmitted in just one of many frequency channels used (e.g., a frequency hopping system), and other frequency channels are likewise measured.

The slave then sends a response packet to the master, and the master uses the packet reception to measure the uplink channel as

$$G_{UL} = G_{S-PA} * \rho * G_{M-LNA} .$$

$$\theta_{UL} = \theta_{S-PA} + \theta + \theta_{M-LNA} .$$

Analogous to the slave measurements,  $G_{UL}$  and  $\theta_{UL}$  are the overall uplink gain and phase shift, respectively;  $G_{S-PA}$  and  $\theta_{S-PA}$  are the gain and phase shift of the slave power amplifier;  $\rho$  and  $\theta$  are again the physical channel attenuation and phase shift, respectively; and  $G_{M-LNA}$  and  $\theta_{M-LNA}$  are the gain and phase shift of the master low noise amplifier, respectively. Figure 2 compares the uplink and downlink.

The response packet sent by the slave to the master includes as data the slave's downlink channel measurements ( $G_{DL}$  and  $\theta_{DL}$ ). The master uses the slave's downlink channel measurements rather than its own uplink channel measurements to adjust its transmission, such as change code rate, information rate, power, antenna weighting, and so forth.

Further, the master computes gain and phase shift calibration factors:

$$C_{gain} = G_{DL}/G_{UP}$$

$$C_{phase} = \theta_{DL} - \theta_{UL}$$

Then when the physical channel changes (master detects this as a change from  $G_{UL}$  and  $\theta_{UL}$  to  $G_{ULnew}$  and  $\theta_{ULnew}$ ), the master applies the calibration factors to update its downlink estimates  $G_{DL}$  and  $\theta_{DL}$  by:

$$G_{DLnew} = C_{gain} * G_{UPnew}$$

$$\theta_{DLnew} = C_{phase} + \theta_{ULnew}$$

The master then uses the updated downlink channel estimates to adjust its transmissions. Note that only at the beginning of a communication session does the slave need to transmit its channel measurements to the master; after the initial transmission the master adjusts using its uplink measurements together with the calibration factors. However, if the communication system uses more than one frequency channel, such as a frequency hopping system does, then the

channel measurements are may in all, or a sampling of, the frequency channels as indicated in Figure 1.

Figure 3 illustrates a method the master uses monitoring the uplink measurement and adjusting the downlink estimate to changes in the uplink measurements.

Figure 4 is a generic transmitter/receiver (transceiver) with a modulator which typically includes a modulation filter for wave shaping to optimize downlink transmission. This wave shaping uses the downlink channel estimates.

The slave can similarly perform calibration computation (using uplink channel information from the master) and track downlink channel measurements to update its uplink channel estimates for more efficient uplink transmissions.

### 3. Reinitialization preferred embodiments

Alternative preferred embodiments have the slave send new channel measurements to the master on a periodic basis so the master can update the calibration factors. The master can compare its updated downlink channel estimates using the old calibration factors and recent uplink measurements with the new downlink channel measurements from the slave and determine how frequently the slave should send new downlink channel measurements.

### 4. Modifications

The preferred embodiments may be varied while maintaining the features of a transmit channel estimate derived from a receive channel measurement together with a previously computed calibration.

For example, the master and slave may be any two of many devices communicating in a wireless system and all devices use the calibration method. Further, the master and slave devices may be symmetrical or asymmetrical such as the master uses multiple antenna beamforming but not the slave, the master has a modulation filter for optimizing downlink transmissions but the slave does not for uplink transmissions, and so forth.